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REVIEW

Detection of Acupuncture Points and Meridians Based on their Electrical Properties: Current Evidence and Future Research Perspectives

Argyrios Periferakis[1,2,3], Konstantinos Periferakis[2,4], Adrian Iftime[1], Lamprini Troumpata[1], Aristodemos-Theodoros Periferakis[1,3], Calina Maier[1,5], Daniel O. Costache[6]

[1] The "Carol Davila" University of Medicine and Pharmacy, Bucharest, Romania; argyrisperiferakis@gmail.com (A.P.); lamprini.troumpata0920@stud.umfcd.ro (L.T.); theodoros.periferakis0920@stud.umfcd.ro (A.-T.P.); adrian.iftime@umfcd.ro (A.I.); calina.maier@umfcd.ro (C.M.)
[2] Akadimia of Ancient Greek and Traditional Chinese Medicine, Athens, Greece; kostas.periferakis@gmail.com
[3] Elkyda, Research & Education Centre of Charismatheia, Athens, Greece
[4] Pan-Hellenic Organization of Educational Programs (P.O.E.P.), Athens, Greece
[5] Panait Sirbu Obstetrics and Gynaecology Hospital Bucharest, Bucharest, Romania
[6] Department of Dermatology, Carol Davila University of Medicine and Pharmacy, Bucharest, Romania; daniel.costache@umfcd.ro

Correspondence: argyrisperiferakis@gmail.com (A.P.); kostas.periferakis@gmail.com (K.P.)

Abstract: Acupuncture is one of the main components of Traditional Chinese Medicine and has been applied as a therapeutical method for centuries. As a therapeutical system, it is based on the use of specific lines in the human body, called meridians, and specific acupuncture points, for choosing the locations where the needles will be applied, depending on the specific problem. In the last few decades, there have been increasing efforts to detect and document the existence of such meridians and points based on at least some of their electrical properties being different when compared to the surrounding skin. A number of researchers have designed experiments, which have had varying degrees of success. Since different researchers have used different experimental setups, and the sample size is usually low, there are issues of validity and comparison between different research results. On the other hand, the majority of available evidence is in favor of there being points and lines characterised by distinct electrical properties, corresponding to acupuncture points and meridians respectively. At the same time, several other theories have been proposed to explain the biological basis of acupuncture points and meridians, while their connection to specific cellular components or neural sequences is an intriguing possibility. While comprehensive research is required to fully document the electrical properties of acupuncture points and meridians, a connection between such properties and their biological basis must also be established.

Keywords: acupuncture points; meridians; electrical properties; TCM; impedance; resistances

INTRODUCTION

Acupuncture is an integrative part of Traditional Chinese Medicine, and has been practised in China [1] and Japan and also in Korea [2, 3] for centuries. It is certain that acupuncture appeared in China although it is difficult to trace its exact historical era of emergence [4]; much later it would be disseminated in Japan, during the 5th century AD [5]. The practises of acupuncture would later become known to Europe by the end of the 17th century, through the works of Willem Ten Rhijne and Engelbert Kaempfer [6]. Following a hiatus of almost a century, after 1850, it would be again be advocated fervently by George Soulié de Morant in 1940s France, and gradually spread to Europe [7].

In the West, there is an ongoing disagreement regarding the efficacy of acupuncture in particular and of alternative therapies in general, both within and outside of the medical community, despite there being numerous studies which are in favour of acupuncture's effectiveness [8-16]; iatrogenic complications and side-effects are also very rare [17]. Even veterinary acupuncture has been gaining traction as of late [18-21], although we will not be dealing with that in the present article; notably, research on acupuncture points has already began in earnest since the 1990s [22,

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23] – there have even been some reports of the effects of acupuncture in plants [24-29]. It has long been accepted by numerous physicians and researchers that acupuncture can be integrated with modern Western medicine [11,30].

In contrast to the methods of Western medicine, also known as "evidence-based medicine", the exact definition of acupuncture points and meridians and the associated "flow of qi", which constitute the principal theory behind acupuncture therapy, is a concept that cannot be quantified and determined accurately by available technical means, at least for now. There are numerous research efforts which have attempted to describe the different electrical properties of acupuncture points.

The different electrical properties of acupuncture points compared to non-acupuncture points in the human body form the basis for the development of special acupuncture point locators, both for somatic and for auricular acupuncture points. It is important to note here that the existence of differences, at some physiological level, between random points and acupuncture points, lends credence to acupuncture being a legitimate therapeutic method more so than mere psychological suggestion [31] or some type of a placebo effect. A research by Vickland et al. [32] suggested that acupuncture changes the electrical properties of the acupuncture points themselves. Even so, the general difficulty in obtaining consistent and reproducible readings in certain points in the skin and the absence of any known physiological mechanism does not allow for a definite determination of the electrical characteristics of acupuncture points [33]. Recently, the advances in machine learning and artificial intelligence [34-39] may allow for different approaches and yield more conclusive results, although nothing definitive is available as of yet. It is possible that a part of the difficulties in establishing a clear-cut model for detecting TCM meridians and acupuncture points has to do with the biological structure of the skin.

The human skin comprises four successive layers, from the exterior to the interior: stratum corneum, living epidermis, dermis, and hypodermis. Detailed investigations into the structure and specific properties of the skin have been made by a number of authors [40-42]. Each of these layers has different conductive, capacitive and dielectric properties; predominantly these depend on the applied voltage although both age [43] and the relative health condition affect them [44]. In essence, parameters such as resistance, impedance and capacitance are a reflexion of the physical properties of the skin [45].

There exist a number of studies, detailing the different skin dielectric properties, depending on the applied voltage, at different frequencies, both for the entirety of the skin layer [46] and for each layer in particular [47-49]. In general, the living epidermis has higher resistivity than the dermis, while the resistivity of the dermis is not as variable. The higher the number of available ions the lower the resistivity values [50]; since the dermis is more hydrated it is reasonable that it has a higher ion content and therefore a lower resistivity [51]. The main component of impedance is the stratum corneum, the most hydrophobic of the skin layers [45]. Another important factor is the relevant permittivity, which reflects the amount of bound charge displacement or polarisation, in a given area, under the influence of an applied electric field [52]. This property is frequency-dependent and is influenced by the existing conditions at a cellular and molecular level [53-55].

In this review, we will present the most important research regarding the determination of acupuncture points and meridians, mostly based on the measurements of electrical parameters, in an effort to interpret their different and sometimes contradictory results. We will also try to interpret these results in the context of the general biological properties of the skin and underlying tissues. As it will become evident, there are a multitude of different studies and methods and we allude to as many of them as reasonably possible, but we have chosen to present in tables only those researches which have focused in measuring electrical properties using electrodes, as this is the focus of our paper. Finally, we will offer possible explanations for the observed phenomena, based on recent discoveries, and directions for future research.

TCM MERIDIANS AND RESEARCH ON THEIR EXISTENCE

There are numerous types of meridian groups, but here, for research purposes we will focus on the 12 principal meridians and the 2 most important extraordinary meridians (Table 1) – to our knowledge no research on locating any other type of meridian, such as collateral or connecting meridians, has been performed using modern methods.

As limb localisation, based on TCM, we define the limb on which most of a meridian's points can be located; most often it also contains the point of origin of the meridian. The time of maximum activity for each meridian indicates when its most active for therapy, and may correspond to the modern concept of circadian rhythms, which has been discussed in many clinical contexts [59-62].

The 12 principal meridians are associated with organs of the human body, although the properties of these organs do not always correspond to those attributed to them by Western Medicine, and medical acupuncture research. For example, in TCM, the Pericardium Meridian corresponds to the "organ" of pericardium, which is however recognised only as an anatomical structure surrounding the heart, and not an organ proper [63,64]. Moreover, Du Mai and Ren Mai do not correspond to any organ but are associated with the regulation of other processes and functions [65,66].

In another example, the Lung meridian is associated with skin health in TCM, a seemingly paradoxical connection by Western medicine standards; however, according to a number of studies, pulmonary pathologies have skin-related manifestations, as is the case, for example of chronic obstructive pulmonary disease [67,68], and of recurring pulmonary capillaritis [69]. In a reverse example, some

skin disorders in children have pulmonary manifestations [70]. While these remarks are interesting and point to a corroboration of many of the principal tenets of TCM, the mainstay of research on verifying the existence of meridians is concerned with identifying them based on their different electrical properties.

Table 1: Principal TCM meridians and their principal characteristics
(based on Soulié de Morant [56], Liangyue et al. [57], Tilikidis [58], and Periferakis [6]).

Western Meridian Name	Chinese Meridian Name	Limb Localisation	Point of Origin	Acupuncture Points in Meridian	Time of Maximum Activity
Lung	Taiyin	Hand	Upper lateral chest, approximately at the level of the 1st intercostal space	11	0300-0500
Large intestine	Yangming	Hand	Radial end of the distal phalanx of the index finger, near the corner of the nail	20	0500-0700
Stomach	Yangming	Foot	Under the eye, directly on the line traversing the pupil, between the eyeball itself and the infraorbital ridge	45	0700-0900
Spleen	Taiyin	Foot	Medial side of the big toe, near the corner of the nail	21	0900-1100
Heart	Shaoyin	Hand	Apex of the axillary fossa	9	1100-1300
Small Intestine	Taiyang	Hand	Ulnar side of the distal phalanx of the little finger, near the corner of the nail	19	1300-1500
Urinary Bladder	Taiyang	Foot	Near the eye in the depression near the inner canthus	67	1500-1700
Kidney	Shaoyin	Foot	Sole of the foot, in the depression former with the foot in plantar flexion	27	1700-1900
Pericardium	Jueyin	Hand	In the 4th intercostal space, by the nipple laterally	9	1900-2100
Triple Boiler	Shaoyang	Hand	Ulnar side of the distal phalanx of the ring finger near the corner of the nail	23	2100-2300
Gall Bladder	Shaoyang	Foot	Lateral to the outer canthus, on the lateral side of the orbit	44	2300-0100
Liver	Jueyin	Foot	Lateral side of the big toe near the corner of the nail	14	0100-0300
Governor Vessel	Du Mai	-	Under the tip of the coccyx	28	-
Conception Vessel	Ren Mai	-	Perineum	24	-

Previous studies on the identification of meridians based on their electrical properties

In general, and compared to the studies on individual acupuncture points, which will be presented on the next section, meridian studies are characterised by a larger sample size and are thus of a higher statistical significance. A number of different measuring techniques were used, and this raises the issues of the comparability and reproducibility of results (Table 2). Probably the earliest research on the different electrical properties of meridians was conducted by Nakatani [71], in the 1950s.

The research of Reichmanis et al. [72] calculated electrical parameters between two different acupuncture points of the same meridian, and determined, using Laplace analysis, that the electrical resistance values were lower. Between the line connecting the two acupuncture points studied, the 14th and 12th of the Large Intestine meridian, there was no other acupuncture point, which could potentially alter the measurements. In the same year, the same authors used the same experimental setup to calculate electrical resistance between the 3th and the 4th acupuncture point of the Heart meridian, with similar positive results [73].

The research of Reichmanis et al. [74] this time measured the resistance between two non-acupuncture points on the Heart meridian; again skin impedance was significantly lower, compared to the control area. This indicates that the presence or absence of acupuncture points in a given meridian area does not affect the clearly different electrical properties of the meridians.

The study of Ogata et al. [75], while not focused on finding the location of meridians based on their electrical properties – indeed it took for granted that the meridians are located on the trajectories described by Traditional Chinese Medicine – detected that there were significant differences in the electrical resistance values of meridians during the different stages of general anaesthesia. We consider the fact that all 12 of the studied meridians had such variations is an, at least indirect, corroboration of meridian location based on different electrical properties, and this is why we included this research. Moreover, we have also included this research in the acupuncture points section of this paper, given that the meridian resistance values were calculated as averages from a number of distinct points in each meridian. Similar results, albeit of a lesser magnitude, were noticed by Ogata et al. [76] in patients under local anaesthesia. Due to the smaller extend of the electrical resistance fluctuation we classify the findings of this research as ambiguous.

It is important to note that the electrical parameters of the skin during post-surgical resuscitation are known to vary, based on the research of Bubnova et al. [77], but it is uncertain if this phenomenon has any bearing on the two aforementioned researches.

Following electrical stimulation at the Jing point of the Stomach (45th of the meridian), 98% of the patients, from a sample of 51 patients tested in an acupuncture clinic, were found to exhibit altered impedance values across the Stomach meridian [78]. The research of Hu et al. [79], which used a larger sample, compared to most of the research efforts examined in this paper, determined that the majority of low impedance points, in the areas examined, where found within a distance of less than 5 mm from acupuncture meridians. Interestingly, they performed this test for all 14 main meridians. A year later, Hu et al. [80] used an electrode moving at an even velocity over the forearm, and computer plotting to demonstrated that most of the detected low skin impedance points were located within the traditional courses of TCM meridians. Similar results were produced by Huang et al. [81], although few details exist on their experiments.

During the research of Zhang et al. [82], impedance was found to be lower in meridians, compared to other skin regions, and to change during needling, a process potentially associated with interstitial fluid fluctuation caused by neuronal reflexes. The research of Martinsen et al. [83], performed using a sample of 20 healthy subjects, did not discover any low resistance trajectories on the volar aspect of the forearm. However, the accuracy of the measuring method of this research has come into question [84]. A subsequent research by Johng et al. [85] yielded positive results, while the research of Ahn et al. [86] had ambiguous findings, in that it demonstrated that the impedance along the Pericardium meridian was decreased, but this was not the case for the Spleen meridian.

The research of Spaulding & Chamberlin [87], who performed acupuncture in order to measure the conductivity across the Large Intestine meridian, yielded statistically significant differences in favour of the meridian, but these were not pronounced enough; thus, we regard these results as being ambiguous.

Table 2: Basic characteristics and outcomes of research of the location of meridians based on their electrical properties

Authors & Reference	Year of Study	Sample Size	Healthy Individuals	Control	Current Used	Experimental Setup	Results	Evaluation
Reichmanis et al. (73)	1977	10	Yes	1-1.5 cm parallel lines medially and parallelly	DC, 1 V	1 cm carbon-impregnated conducting rubber electrodes (modified LIDC electrodes by Ritter Co.)	The electrical resistance values in the line connecting the two acupuncture points were lower compared to the control	Positive
Reichmanis et al. (72)	1977	10	Yes	1-1.5 cm parallel lines medially and parallelly	DC, 1 V	1 cm carbon-impregnated conducting rubber electrodes (modified LIDC electrodes by Ritter Co.)	The electrical resistance values in the line connecting the two acupuncture points were lower compared to the control	Positive
Reichmanis et al. (74)	1979	10	Yes	1.5 cm parallel lines medially and parallelly	DC, 1 V	1 cm carbon-impregnated conducting rubber electrodes (modified LIDC electrodes by Ritter Co.)	The electrical resistance values in the line connecting the two non-acupuncture points were lower compared to the control	Positive
Ogata et al. (75)	1983	10	No	None	AC*	Standard ECG electrodes taped over the chosen acupuncture points in each meridian; values measured during various intervals from preanaesthesia to postanaesthesia	There was a decrease of up to 36 % in skin resistance in 10 of the 12 studied meridians, and by a maximum of 100 % and 73 % on the kidney and bladder meridians respectively	Positive
Ogata et al. (76)	1983	6	No	None	AC*	Standard ECG electrodes taped over the chosen acupuncture points in each meridian; the values were measured before and after the application of local anaesthesia	There were fluctuations of a rather small scale in all of the meridians studied	Ambiguous

Xiang et al. (78)	1984	51	No	None	AC, 0-100 V	Stimulation of the Stomach Jing point using a bipolar electrode and measurements based on the process of Zhu et al. (88)	A distinctly localised meridian line for the Stomach was located in the overwhelming majority of subjects after the initial stimulation	Positive
Hu et al. (79)	1992	68	Yes	Areas laterally removed from the meridians	DC, 0-50 V	1 mm pure Ag tip electrode	The majority of the studied points within less than 5 mm from all 14 main meridians was found to have low impedance	Positive
Hu et al. (80)	1993	12	Yes	Areas not belonging to established meridians	AC†	Exploratory electrode moving at a standard velocity over the forearm – computer system used for plotting	Low skin impedance points (LSIPs) were discovered and were generally distributed along known meridian courses	Positive
Huang et al. (81)	1993	25	Yes	Areas not belonging to established meridians	AC†	n/a (perhaps similar to the setup of Hu et al. (80))	Low skin impedance points (LSIPs) were discovered to lie mostly within or very near to known meridian courses	Positive
Zhang et al. (82)	1999	12	Yes	Non-acupuncture points in surrounding skin	AC	4 electrode technique – 4 mm diameter pipes with saline cotton	There was a decrease in impedance in the meridian area studied, which fluctuated during needling	Positive
Martinsen et al. (83)	2001	20	Yes	None	AC	16 electrode (0.5 mm diameter) linear array	No linear low resistance trajectories were detected	Negative
Johng et al. (85)	2002	30	Yes	Lateral parallel control at a distance of 6-7 cm from the tested meridian	AC	4 electrode technique similar to that of Zhang et al. (82)	Higher capacitive effects at acupuncture meridians, compared to the control	Positive
Ahn et al. (86)	2005	23	Yes	Control segments 0.8 cm distant, medially and parallelly to the tested meridians	AC	4 electrode method (0.25 mm Au plated needles serving as the electrodes) supplemented by ultrasound imaging of the connective tissue planes along the tested meridians	While impedance in the case of the Pericardium meridians was indeed lower, the same cannot be said for the impedance of the Spleen meridian	Ambiguous
Spaulding & Chamberlin (87)	2011	20	Yes	Non-meridian tissue	AC†	A test configuration involving a data acquisition hardware, while processing was performed in Matlab; acupuncture was performed during the measurement	There is a somewhat better conduction along the Large Intestine meridian, compared to non-meridian tissue; while there is a statistical significance of the values, these are not dramatic	Ambiguous

** For these researches the exact data on the type of current used are not available; therefore, based on their use of ECG electrodes and apparatuses we have assumed that it is AC current (this being the more common modality in such machines)*
† Similarly, no data on the current type were mentioned and we have assumed it to be AC, which is the most common setting

The particular research parameters of the aforementioned studies on meridian locations are presented in the table below (Table 3).

As can be seen, meridian studies have a higher mean sample size, compared to the acupuncture point studies, which will be presented in the following chapter. In general, there is a greater homogeneity of in research methods and subject selection compared to the following studies on acupuncture points presented in the next section.

The studies with control have also used healthy subjects and there is about an equal number which used AC and DC; most of them have results which can be evaluated as "successful''. The fewer and more diverse studies with no control have also had a relatively

positive total outcome. Of course, it is easier to locate meridians compared to acupuncture points, as acupuncture point location is a more difficult and precise process.

In the next subsection, a number of studies on locating meridians using other methods were presented. The association between meridians and interstitial fluid has also been explored by a number of authors along with a number of other proposed alternatives

Table 3: Data on the presented research on meridians

Study Type	N	Mean Sample Size	Subjects' Health			Type of Current Used			ReportedOutcome		
			Healthy	Not Healthy	Mixed	AC	DC	Both	Positive	Ambig.	Negative
Studies with control	10	22.00	10 (100%)	0 (0%)	0 (0%)	6 (60%)	4 (40%)	0 (0%)	8 (80%)	2 (20%)	0 (0%)
Studies with no control	4	21.75	2 (50%)	2 (50%)	0 (0%)	4 (100%)	0 (0%)	0 (0%)	2 (50%)	1 (25%)	1 (25%)
Total studies number	14	21.90	12 (85.7%)	2 (14.3%)	0 (0%)	10 (71.4%)	4 (28.6%)	0 (0%)	10 (71.4%)	3 (21.4%)	1 (7.2%)

For example, Li & Zhao [89] proposed that meridians may coincide with the courses of some blood vessels, while Zhu [90] proposed that the meridians as explained by the TCM are, in fact, an erroneous representation of the nervous system. Several hypotheses were proposed by Zhang [91] while the current research consensus focuses on the meridians representing low hydraulic resistance channels associated with the movement of interstitial fluid and specific metabolites [92]. The association of meridians with stem cells was also proposed by Pawitan [93]; bearing in mind that the stem cell potential varies with a number of factors [94-100], this could have a bearing on the differences in meridian studies across individuals.

Other Studies and Theories on the Properties and Location of Meridians

Apart from the more traditional method of detecting and/or identifying meridians based solely on their different electrical properties, a number of authors have tried a variety of different approaches (Table 2). The most probable explanation is that the different electrical properties of meridians are based on a neural electrical field [101].

The tentative research of Jiang et al. [102] indicates that along meridians, the microcirculatory response to moxibustion therapy is different; thus it may be inferred that there may be well be some level of difference in the microvasculature of meridians, compared to other locations on the body. Research suggests that, in rat experiments, moxibustion therapy seems to modulate gene expression [103]. A clinical trial protocol on the same principle was proposed by Hu et al. [104]. On a different note, the research of Lin et al. [105], indicated that the electrical flow across meridians changes depending on acupuncture needle manipulation during therapy.

Crucially, as is also the case for certain acupuncture points, the electrical properties across meridians seem to differ between pathological and healthy conditions [106,107]. On a related note, a potential association between electrical resistance changes and pain after orthopaedic surgery, which however warrants further investigation, was proposed by Rezvani et al. [108].

The most currently prominent avenue of research on defining the morphofunctional characteristics of meridians centres on them being supposedly channels where a higher amount of interstitial fluid is found. A gel model based on this concept seems to suggest that there is some merit in this theory [91]. An earlier research by Zhang et al. [109] in rats, had not produced any corroborating results.

Finally, the different electrical properties of meridians may be associated by an ion drift theory, as proposed by Liu et al. [110]; notably the research of Lee et al. [111] also mentioned that the special properties of acupuncture points may be associated with different ion concentrations.

VARIATION OF SKIN ELECTRICAL PROPERTIES AT ACUPUNCTURE POINTS

The classical Chinese theory postulates that there exist over 300 acupuncture points, distributed across the 12 principal and 2 extraordinary meridians mentioned above, all over the human body.

The stimulation of these points, based on the view of traditional acupuncturists, adjusts the "qi flow" along the human body; the most frequent proposed interpretation for this notion of "qi energy" is electrical energy [112] and this has been the focus of the majority of meridian detection-associated research.

Electrical properties of acupuncture points – Research history

While, based on the traditional theory, the location of points is determined based on the anatomical parameters and locations of the human body, it was though also possible that these points exhibit distinct electrical properties; based on this speculation, relevant research was performed in the 1950s ([33,113]; and references therein), documenting that at least some acupuncture points where characterised by specific electrical properties.

Table 4: Basic characteristics and outcomes of research of the location of acupuncture points based on their electrical properties

Authors & Reference	Year of Study	Sample Size	Healthy Individuals	Control	Current Used	Experimental Setup	Results	Evaluation
Reichmanis *et al.* (122)	1975	7	Yes	Anatomically similar location within 1 cm^2	DC, 8 V	1.5 mm measuring electrode and a specially designed wheel electrode; both made from stainless steel	Most of the acupuncture points measured were identified based on their electrical parameters in all subjects	Positive
Reichmanis *et al.* (123)	1976	10	Yes	Suitable nearby anatomical location	DC, 2 V	36 stainless steel rods in a grid pattern over the acupuncture point	Over 75% of the acupuncture points were electrically different compared to the control areas	Positive
Hyvärinen, & Karlsson (124)	1977	5	Yes	Surrounding skin	DC, 6.7 V	0.5 mm circular electrode and 2.5 mm reference electrode	Points of consistently low electrical resistance, resembling acupuncture points, were identified	Positive
		5	Yes		DC & AC	0.5 mm silver wire	Massively lower, about 50-100 times, electrical resistance was identified in the same points as above	Positive
McCarroll & Rowley (125)	1979	8	Yes	None	AC (V is a measured variable)	5 x 5 grid with the acupoint in the centre	The decreased electrical impedance detected at a few points was attributed to temporal variations and the pressure of the probe on the stratum corneum	Negative
Poon et al. (127)	1980	9	Yes	Surrounding skin	AC, 0-18 V	Special epiductive tape electrode	Numerous spots of increased conductance were identified, many lying across the meridians, but a lot differing significantly from conventional acupuncture locations	Ambiguous
Jakoubek & Rohlícek (129)	1982	n/a	n/a	n/a	DC & AC	Multiple electrodes	Many points with increased electrical conductance, corresponding to acupuncture points, were detected	Positive
Ogata et al. (75)	1983	10	No	None	AC[†]	Standard ECG electrodes taped over the chosen acupuncture points in each meridian; results measured during various intervals from preanaesthesia to postanaesthesia	There were marked electrical resistance variations during the different stages of anaesthesia, in most of the acupuncture points studied	Positive
Ogata et al. (76)	1983	6	No	None	AC[†]	Standard ECG electrodes taped over the chosen acupuncture points in each meridian; the values were measured	There were fluctuations of a rather small scale in all of the individual points measured	Ambiguous

						before and after the application of local anaesthesia		
Margolin et al. (131)	1996	34	No	Auricular control zones not comprising any acupuncture points	DC	Specially developed device with a 1 mm Ag/AgCl electrode composition; use of biogel as a conducting medium – the measurements were performed using auricular acupuncture points; subsequent acupuncture of both control and active points was performed	The therapeutic effects of acupuncture in low impedance points were not very much different from the effects on non-acupuncture points	Ambiguous
Zhang et al. (82)	1999	12	Yes	Non-acupuncture points in surrounding skin	AC	4 electrode technique – 4 mm diameter pipes with saline cotton	There was a decrease in impedance in the meridian area studied, which fluctuated during needling	Positive
Falk et al. (130)	2000	34	No	Control zones on the helix of the ear	AC	An Ag/AgCl probe of 1 mm diameter in a 2 x 2 grid	The sites of lowest impedance were identified as being within active zones	Positive
Zhang et al. (138)	2004	12	Yes	Two points on either side of the low impedance points at a distance of 0.5 cm	AC	Four-electrode impedance instrument (Korean SPAC instrument) based on the methodology described by Zhang et al. (82)	It was found that 71 % of the acupuncture points tested had a lower impedance compared to the control points	Positive
Lee et al. (139)	2005	20	Yes	One non-acupuncture point	DC, 1.28 V	Electrodes affixed to two acupuncture points and one non-acupuncture point; constant pressure applied in the 4th point of the Large Intestine Meridian	Meridian points exhibit a greater conductivity compared to non-meridian points	Positive
Pearson et al. (141)	2007	20	Yes	Nearby control sites no more than 5 cm away from the acupuncture points	DC & AC	Prognos instrument (4.57 mm probe tip) along with a specially designed PT probe	None of the acupuncture points measured exhibited lower impedance values compared to the control points	Negative
Kramer et al. (142)	2008	43	Yes	Surrounding skin	DC, 4.8 V (mean)	Specially designed array comprising 64 electrodes covering an area of 36 cm^2	Only about 1/3 of the measured acupuncture points exhibited significantly decreased electrical resistance values	Negative
Kramer et al. (143)	2009	53	Yes	Surrounding skin	DC, 4.8 V (mean)	Specially designed array comprising 64 electrodes covering an area of 36 cm^2	Some acupuncture points displayed elevated and some reduced impedance values compared to the surrounding areas; it is therefore considered possible that acupuncture points possess different transient electrical properties compared to the surrounding skin	Ambiguous
Rezaei et al. (144)	2012	18	Yes	Parallel series of four control needles placed 0.8 cm	AC	4 electrode technique specifically designed for the study in question	The point studied (PC4) was found to be electrically distinct from other non-meridian points and similar	Positive

				medial to the meridian needles			to other points of the same meridian	
Wong (145)	2014	65	Yes	A neighbouring non-acupuncture point, 2 cm distant	DC, 0.5 V	Bipolar electrode (3 mm in-between electrodes) and a sensing probe	The point studied (LI14) was not found to be electrically distinct from the control point	Negative

** For these researches the exact data on the type of current used are not available; therefore, based on their use of ECG electrodes and apparatuses we have assumed that it is AC current (this being the more common modality in such machines)*
† Similarly, no data on the current type were mentioned and we have assumed it to be AC, which is the most common setting

Some decades earlier, in the 19th century, August Weihe (1840-1896), a medical doctor and homeopathy practitioner came to the conclusion that specific points in the human body were found to be more painful compared to the others, following the ingestion of a toxic quantity of certain homeopathic remedies [114]; it has been mentioned that Weihe knew the notion of specific therapeutic points from a relative in China [115]. It is also notable that Soulié de Morant mentioned that these points coincided with Chinese acupuncture points [116]. The theory of homeosiniatry was proposed by Roger de la Fuye (1890-1961), in 1932, to account for the physiological similarities between homeopathic remedies and acupuncture points; notably, he impregnated some acupuncture needles with homeopathic remedies in a number of his acupuncture therapies [116]. Today, both Weihe and de la Fuye are considered as the ancestors of the theory of electroacupuncture [117]. In 1953, probably the first electroacupuncture apparatus was designed and built by R. Voll (1909-1989) and F. Werner [113].

Despite many studies having taken place on this subject (Table 4), some of them are deemed as being of poor quality, due to a number of factors [118]. A particular point in researching the electrical properties of acupuncture points is the standard to which the data obtained are compared with; more precisely, while acupuncture points may not present minimal electrical resistance at an absolute level, the issue is if they exhibit a different electrical resistance compared to their surrounding tissues. Dedicated research to for the particular, if any, electrical properties of acupuncture points began in the 1970s; notable research efforts from this era are those of Frost & Orkin [119] and Kaslow [120]. Contemporary views on the existence and function of acupuncture points in particular and acupuncture in general can be found in McCarroll [121].

The research of Reichmanis et al. [122] was based on the principle that acupuncture points exhibit a reduced electrical resistance [30]; accordingly, they aimed to prove that acupuncture points exhibited a distinct resistance minimum compared to the surrounding tissue. They employed direct current and used some of the most easily accessible points of the Large Intestine (LI) and Pericardium (Per) meridians; they concluded that all of the studied points exhibited an increased electrical conductance, relevant to the surrounding tissues and most could be located in the majority of subjects. In a subsequent research [123], using a 36 rod grid, on skin disinfected with 90 % alcohol and moistened with tap water, over selected acupuncture loci; suitable control areas were also selected. The points selected were again easily accessible, from the Triple Boiler (TB) and Lung (Lu) meridians. Most, but not all, points were detectable based on different electrical parameters. Further promising results were obtained by Hyvärinen & Karlsson [124], who detected a number of low electrical resistance points on the forearm, hands and ears, which resembled acupuncture points, albeit in a small sample of five healthy individuals. Similarly, in these points the electrical impedance values were found to be massively lower compared to the surrounding skin [124].

Despite these positive results, McCarroll & Rowley [125], who measured the electrical conductance in certain acupuncture points in the hands and arms, came to an unfavourable conclusion. It is noteworthy that this study considered extensively the probable consequences of the pressure applied by the electrode on the skin, to the measurements; in addition, it considered whether any break in the stratum corneum may influence the results. The authors mentioned that, based on their measurements, the time-dependent nature of skin conductance, as asserted by Geddes & Valentinuzzi [126], applied to their measurements as well. They concluded that any detected variations were the result of differing electrode pressure on the stratum corneum and the temporal variability of skin conductance [125].

In an effort to minimise the effect of the electrode itself, Poon et al. (127) used a special epiductive tape electrode, based on the method of Burton & Maurer (128). They determined that a number of points which had different electrical properties corresponded with acupuncture points, but other such points did not; moreover, no statistical analysis demonstrated that across all subjects no significant coincidence between electrically "special" points and acupuncture points was revealed. Even more strikingly, the points of good conductance differed between the two arms of the same subject (127). In addition, a number of low resistance points coinciding with acupuncture points were detected in both humans and rats, and also some such points – not corresponding to acupuncture points – were found in areas of referred pain (129). The research of Ogata et al. (75), to which we have already referred to in the meridians section, also noted that electrical properties of acupuncture points changed during different stages of anaesthesia. For the same reason, the other research of Ogata et al. (76) is included in this chapter too.

A four-electrode method was employed by Zhang et al. (82) to evaluate a single acupuncture point, the 3rd of the Pericardium meridian, during, before and after needling, compared to a number of control points. It was noted that electrical impedance changed in all points, but the impedance reduction in acupuncture points was greater; it was theorised by the researchers that the impedance decrease was owed to a transient increase of interstitial fluid during needling, which is most probably associated with an axonal reflex and/or blood capillary expansion (82). We have already included this research in the section on meridians, but we also place it here because of its focus on the area around a single point.

Meanwhile, Falk et al. (130), using as test subjects patients under treatment for cocaine addiction, detected significantly lower impedance values in the active zones of the ear, i.e. those corresponding to auricular acupuncture points. A similar research had already been conducted by Margolin et al. (131), who tested the differential efficacy of acupuncture treatment in high and low impedance points in the ear; the results in this clinical trial had been ambiguous, in that while needling in low impedance points – corresponding to acupuncture points – had somewhat better effects, this difference was assessed as not being significant enough. Again, this therapeutic approach concerned auricular acupuncture in cocaine addicts. Interestingly, during auricular acupuncture it proved impossible for the subjects to identify, based on pain perception, when acupuncture points were needled, or when needle placement was random (132). Incidentally, there is as of yet no consensus regarding the efficacy of auricular acupuncture in treating cocaine addiction; the results range from mildly encouraging (133, 134) to inconclusive (135, 136) or even negative (137).

Using the four-electrode method, Zhang et al. (138) determined that in their research on a small number of heathy subjects, 71 % of the acupuncture points had a significantly lower impedance compared to the control points on either side. The research of Lee et al. (139) suggested that between two acupuncture points the conductance was greater than between a non-acupuncture and an acupuncture point. Since the second pathway did not belong to an established meridian, they concluded that their experiment perhaps corroborated the theory of Chen (140), who proposed that the dielectric constant along meridians is lower compared to other non-meridian trajectories. Contrary to this, the research of Pearson et al. (141), which was one of the most well-controlled studies, did not detect any significant differences in electrical impedance between acupuncture and non-acupuncture sites.

The research of Kramer et al. (142), who studied the variations of electrical skin resistance in the 34th point of the Gall Bladder meridian in 43 healthy volunteers concluded that, compared to the surrounding skin, only about 33% of the studied points exhibited statistically significant differences; they rightly considered such a small percentage to not be in agreement with most other performed research. A subsequent clinical trial (143) yielded ambiguous results.

The research of Rezaei et al. (144) aimed to determine if a certain acupuncture point, the 4th of the Pericardium meridian, had any different properties compared to its surrounding ones and other points in the same meridian; it was found that it was electrically distinct compared to non-meridian points, but not so much compared to meridian ones. The four-electrode method employed was based on the research of Zhang et al. (82).

The research of Wong (145) is particularly important, as it strived to do stringent lab-controlled measurement of skin resistance of an acupuncture point (14th point of Large Intestine Meridian) on a larger sample (65 participants) than other studies. In their larger sample, they found no statistically significant difference in the electrical resistance between acupuncture and non-acupuncture points.

The results from all the studies in Table 4 are presented in the following table (Table 5), in order to enable a more complete view of the current research consensus.

Table 5: Data on the presented research on acupuncture points

Study Type	N	Mean Sample Size	Subjects' Health			Type of Current Used			ReportedOutcome		
			Healthy	Not Healthy	Mixed	AC	DC	Both	Positive	Ambig.	Negative
Studies with control	15	23.1	13 (86.7%)	2 (13.3%)	0 (0%)	5 (33.4%)	8 (53.3%)	2 (13.3%)	9 (60%)	3 (20%)	3 (20%)
Studies with no control	3	8	1 (33%)	2 (66%)	0 (0%)	3 (100%)	0 (0%)	0 (0%)	1 (33%)	1 (33%)	1 (33%)
Total studies number	18	20.6	14 (77.8%)	4 (21.2%)	0 (0%)	8 (44.5%)	8 (44.5%)	2 (11%)	10 (55.6%)	4 (22.2%)	4 (22.2%)

As it can be easily seen from the aforementioned concise table on research results, the studies with control have a considerably larger sample size compared to the studies with no control, where its absence along with the limited sample size further undermines their statistical significance.

In assessing the more significant first group of studies, the overwhelming majority used healthy subjects, while half of them used direct current. Only a small percentage were negative, while the majority was positive or ambiguous. The results were equally distributed in the second group of studies; overall, about half of the studies presented in this section were unambiguously positive, although we would suggest that this statistic has been negatively skewed due to results from the studies with no controls. The majority of studies selected healthy subjects only, while the most frequent current used was alternating current by a small margin, followed by direct current; very few studies opted for both currents.

The relative discrepancy in results can be partly, in our opinion, explained by the fact that the majority of studies have limited their measurements in the upper limbs. The most recent research indicates that acupuncture point resistance values are non-linear [146] and this may influence the results, because on one hand some researches may have focused in non-optimal areas, and on the other few data on the lower parts of the body, and the head exist, if any at all. It is, however, a fact that electrical resistance measurements exhibit great variations depending on anatomical locations [118].

A curious phenomenon, termed the “drift” effect, was discovered by Mayer-Gindner et al. [147], where, if alternating current (AC) is used by the electrode, in the same point, gradually the electrode-skin resistance will decrease. They proposed that at least 20-30 min, if not 40-50 min should pass between two consecutive measurements, even if the point measured is not the same but an adjacent one. They suggested a new method for locating acupuncture points using alternating current. However, this does not seem to be the case, at least to our knowledge, as 5 out of 6 control-group AC studies yielded a positive result.

Presumably, the same influence of the circadian rhythm on meridians, if confirmed, should apply also to acupuncture point measurements. It is known for certain that the circadian rhythm affects skin physiology [148]. The circadian rhythms are also known to affect skin hydration [149], a factor which for sure influences the electrical resistance of the skin and potentially the detectability of acupuncture points.

In addition, there are evidence which suggest that the partial oxygen pressure values in the tissues underlying the meridians are higher than the tissues under random anatomical sites [150]. We mention this research here, instead of the previous meridian chapter, since it was performed on acupuncture points but in essence concerns the whole meridians trajectories. The extensive scientific literature in matters other than electrical properties per se, as outlined in the previous section, seems to corroborate the existence of acupuncture points as distinct morphofunctional entities.

We may conclude that regardless of whether the loci of low electrical resistance can be considered as being the same as the acupuncture points of TCM or not, it is by far more probable that such distinct loci do exist. Their diameter ranges from 1 mm to about 4 mm [120,151,152]. A factor which complicates matters is the relative uncertainty in locating acupuncture points [153], as based on textbooks there may be slight variations [154]; taking into account the tiny diameter of the loci of decreased resistance, it is conceivable that some negative research outcomes were influenced by a slightly erroneous choice of measurement sites. Research on whether needling of the exact location is necessary for a successful treatment outcome is still ongoing [155]; perhaps a general location with a diameter of some mm with the locus of minimum impedance at the centre may be considered as an acupuncture point. What is more certain is that the stimulation of acupuncture points, or of areas around them at least, is by far more effective that the stimulation of random, non-acupuncture points, based on a number of studies [156-160].

Other studies and theories on the properties of acupuncture points

There are a number of other studies, which are associated with the particular properties of acupuncture points, but which do not adhere to the pattern thus described, i.e., the comparison between acupuncture and non-acupuncture points in terms of their electrical properties. The effort of morphologically defining acupuncture points has begun since the late 1970s [161] and it is still an ongoing field of research, where many suggestions and research results must be taken into account. From a structural standpoint, it has been proposed that the microvasculature is capable of providing a larger blood supply in acupuncture points [162].

For example, Liang et al. [163] have asserted that the NO (nitric oxide) concentration in the skin, in acupuncture points, is higher compared to non-meridian and non-acupuncture points. According to their experiment, a NO-noradrenaline system is associated with the different electrical resistance at acupuncture points. Their experiment was based on the previous findings of Chen & Ma [164]. In the same year, Ma [165] asserted that, in addition to the NO-noradrenaline system, the reduction of nitrates by bacteria at acupuncture points was also contributing to the different electrical properties. Other relevant studies, with quite favourable results also exist [166-169].

A limited research effort by Khorsand et al. [170] used an entirely different setup, in that it evaluated the changes of electrical properties of acupuncture points before and after acupuncture was performed – none were detected. A study by Turner et al. [171] aimed to ascertain whether, between arthritis patients which experienced pain and pain-free arthritis patients, there would be any difference between the electrical properties of certain acupuncture points. They concluded that patients which felt pain had different resistance values at acupuncture points, and ventured to suggest that the different electrical energy flow in these patients might be seen as a connection between Western and Chinese medicine concepts.

Ambiguous results, regarding menstrual pain, were yielded by She et al. [172]; the authors do remark, however, that it is a promising field for further investigation. Indeed, following a recent thermographic analysis, Xisheng et al. [173] suggested that a number of acupuncture points is sensitised in patients with primary dysmenorrhea. Interestingly, based on Xu et al. [174], the electrical resistance of specific acupuncture points changes with the variations of blood flow in the uterus, during the menstrual cycle, a result also previously yielded by the research of Wei et al. [175]. At any rate, a nerve-related model to explain acupuncture analgesia was put forward by Silberstein [176]. The values of the electrical properties of a number of acupuncture points were also found to be different in encephaloma patients undergoing surgery [177].

It is also compelling to consider the implications of the research of Weng et al. [178] who suggested that electrical conductance was different between healthy and obese patients, and in fact changed as those obese patients started losing weight.

Recently, an emerging theory suggested that at least some acupuncture points may be thermically distinct between healthy and unhealthy states [179]; this is also a promising field for future research. An earlier review on the subject [180] was more assertive in acupuncture points having a distinct thermal profile, but this is not a unanimously supported conclusion. The infrared profile of acupuncture points may also be of interest in determining the best course of acupuncture therapy [181]. Another study, focusing on asthma patients, suggests that it may be possible to use the values of electrical impedance at certain acupuncture points for screening and treatment effectiveness purposes [182].

The individuality, so to speak, of acupuncture points maybe also be attributable to their differing, compared to the surrounding tissue, ion concentrations, as suggested by the research of Lee et al. [111]. A number of inorganic ions, such as Ca^{2+} and Mg^{2+} are distributed prominently on the upper delimitation of the stratum granulosum [183-185], while the distribution of other ions varies in the other layers [184-187]. We might thus suggest, that from a morphological point of view, the distinct acupuncture points represent areas where, for some reasons, there is a differential horizontal and lateral ion distribution across the skin layers. Interestingly, given that the upper stratum corneum is permeable to external substances [188-191], its ionic profile can theoretically be externally modified; thus, by modifying the electrical resistance of acupuncture points it may be possible to modify treatment efficacy.

It must also be noted that, according to the review of Colbert et al. [192], there is an important clinical utility in assessing the variations of electrical properties in acupuncture points, given that they might reveal latent pathologies or be associated with a state of physical exhaustion. The stimulation of acupuncture points with chemical means, also has therapeutical effects as suggested by a number of researchers [193-196]. Regarding this aspect, it is interesting to remark that drug administration in acupuncture sites seems to be more effective compared to non-acupuncture sites [197]. Furthermore, the research of Periferakis & Periferakis [198], in a sample of 40 patients, both healthy and not, using the Pointo Select DT device, for detection of auricular acupuncture points, determined that in the majority of cases, most, but not all points are easily detectable.

An interesting concept is that of neuronal acupuncture [199], which is based on the premise that in acupuncture points, specific neuronal and neuroactive components are stimulated; these loci could comprise the 361 WHO-accepted acupuncture points [200]. The concept of neuronal acupuncture could perhaps be used to explain how or why acupuncture points exhibit different electrical properties, compared to the surrounding skin.

Finally, Cho et al. [201] measured biopotential differences between acupuncture and non-acupuncture points during acupuncture treatment; acupuncture points seemed to have greater variability which seems to be related to the classical concept of the “flow of Qi”. Even the practicing of Qigong, which is theorised to affect Qi circulation, results in significant changes of the electrical potential of acupuncture points [202]. It has also been documented that with needle placement in certain acupuncture points it is possible to observe electrocardiogram and electroencephalogram changes [203,204]; changes where affected during stimulation of non-acupuncture points also, but needle placement in acupuncture points produced more pronounced changes [204].

DISCUSSION

Research on the properties of acupuncture points and meridians has been one of the most prominent topics amongst relevant scholars [205]. It is obvious from the presented studies, that many different researchers have evaluated the identification of acupuncture points based on their electrical parameters, but many of these methods differ significantly, and it is little wonder that their results are not comparable. Of particular interest, however, is the fact that the voltage selected each time seems not to affect the results, i.e., a different voltage will not turn a low impedance point into a high impedance one [206], so at least this offers a modicum of result comparability even if the experimental parameters differ.

Nonetheless, it must be stressed that a host of factors from the parameters of the electrodes, to the physiological and psychological status of the subjects, to the frequencies used, affect the detection of low impedance points [85,207]; therefore, many research results may be rendered inaccurate, and this may also explain the discrepancies in-between the values even of positive-outcome research efforts. Another research by Prokhorov et al. (208) suggest that between racially different populations, the DC measurements of skin resistance are not comparable, a factor which must also be taken into account in future studies. A useful summary of confounding factors in acupuncture point detection research is provided by Luo et al. [209]. It should be noted here that considerable

variations in the localisations of acupuncture points is a fairly common occurrence even amongst experienced acupuncturists [210], i.e., the discrepancies are not limited to apparatus-based location methods.

Current research efforts and their significance

Based on the cumulative research results on both the meridian and acupuncture studies (Table 6) we can see that the majority of them where positive, in that it was possible to identify electrically distinct locations and lines on the surface of the human body. Most of the studies used DC, although an almost equal number used AC, and only 2 used both types of current. Finally, the mean sample size was 21.2 subjects. It is difficult to conclude here what the optimal sample size should be for such a research, as there are quite a number of factors which influence its size [211]; moreover, the statistical significance of a sample does not directly in itself validate the experimental results [212]. However, since meridians and acupuncture points, should, in principle, be detectable in any individual, for this particular type of studies, even a small sample should suffice to determine the outcome. However, as mentioned by Reichmanis et al. [123], not all acupuncture points are detectable at all times, and this may be important for the therapeutic efficacy of acupuncture in different patients, or for different protocols used on the same patient. Anomalies in the detectability of acupuncture points, specifically for auricular acupuncture, have been reported by Periferakis & Periferakis [198].

Table 6: Combined and comparative data on the detection of acupuncture points and meridians based on their electrical properties

Study Type	N	Mean Sample Size	Subjects' Health			Type of Current Used			ReportedOutcome		
			Healthy	Not Healthy	Mixed	AC	DC	Both	Positive	Ambig.	Negative
Studies with control	25	21.9	23 (92%)	2 (8%)	0 (0%)	11 (44%)	12 (48%)	2 (8%)	17 (68%)	5 (20%)	3 (12%)
Studies with no control	7	20.6	3 (42.9%)	4 (57.1%)	0 (0%)	7 (100%)	0 (0%)	0 (0%)	3 (42.8%)	2 (28.6%)	2 (28.6%)
Total studies number	32	21.2	26 (81.3%)	6 (18.7%)	0 (0%)	18 (56.3%)	12 (37.5%)	2 (6.2%)	20 (62.5%)	7 (21.9%)	5 (15.6%)

A number of meridian and point locator devices have entered the market after the 1970s [138]. Given the differences in approaches and the fact that even with complicated experimental setups results cannot always be obtained, it is no wonder that the efficacy of early acupuncture point detectors, based on the properties of the points themselves, was called into question [213]. Newer and more sophisticated devices and sensor arrays, such as those proposed by a number of authors [214-216] may improve detection results and eliminate ambiguity.

Regarding research purposes, the delayed luminescence method [217] and the low energy laser (LEL) coherent light interaction with skin [218] may be of future use in evaluating the dielectrical properties of acupuncture points. The more modern method of electrodermal mapping may prove even more useful [219]. Indeed, in the recent years measuring reliability seems to have improved considerably [220].

Finally, the variations and importance of electrical resistance will prove useful even in considering the physical composition of the needles themselves; recent evidence suggests that by some specific material treatment methods it is possible to affect electrical resistance and therefore the therapeutic potential of the treatment [65]. At any rate, as discussed elsewhere, the electrosensitivity of acupuncture points may be a useful clinical and treatment marker [221]. Bearing in mind that there are a number of proposed mechanisms for the action of acupuncture [222], there exists a host of potential modifying factors in assessing the function and potential of acupuncture points and meridians.

Potential Future Directions of Research

Regarding attempts at a structural and biological interpretation for the existence of acupuncture points and meridians, there exists a number of recent research attempts regarding evidence on a cellular level. The most recently discussed theory is that telocytes may be the underlying biological bases of meridians. This is a specialised type of interstitial cells [223], with cytoplasmic extensions; such a structural particularity enables the communication with other distant cells [224]. Telocytes have been found to reside in a number of different tissues [225-232]. Although appearing similar to some other specialised cells types, both telocytes themselves and their extensions, the so-called telopodes are structurally different [233]; the telopodes are expressed both in the body and in cell cultures [234]. There are many theories on what their exact function may be [235-238], but as of yet there is no consensus. A detailed investigation into the potential association between telocytes and TCM meridians was performed by Yonghong et al. [239], on tissues of different animals. Indeed, it was proved that there exist both homocellular and heterocellular connection between telocytes and telocytes and other cell types respectively [239]. Since telocytes interconnect smooth muscle cells, glandular cells and cells for

different organs, along with nerves and other structures, this could be the long-elusive network enabling the stimulation of superficial skin structures to have an effect on distant and apparently unrelated morphofunctional units. Notably, as Yonghong et al. [239] assert, the existence of telocytes could be a basis for the interpretation of all the current meridian-associated theories proposed by numerous authors [240-244]. Despite the promising aspects of telocyte research, it must be noted that, as of yet, and to the best of our knowledge, it has proven impossible to interpret all the physiological and pathological connections mentioned in TCM using the notion of telocytes. This of course might be traced down to the fact that telocytes are dynamic cells, so that static imaging techniques may not be always able to trace the full extent of their network. Alternatively, there might be telocytes that are sometimes overlooked in research for a number of reasons [245]. Or, apart from the two aforementioned constraints, it may just so happen that telocytes are not the only answer to this conundrum. Interestingly, a telocyte-based mechanism for the cure of ulcerative colitis by acupuncture was recently proposed by Bai et al. [246].

Another theory on what is the biological basis for meridians and acupuncture points involves keratinocytes, the most dominant cell type of the epidermis [247]. Regarding their electrical activity, it is known that they possess physiologically, a variety of transient receptor potential channels [248-253], along with a number of other channels and receptors [254, 255]. Based on this aspect, and on the experimental research of Denda & Tsutsumi [256], it is hypothesised that it is possible for keratinocytes to generate spatially restricted signalling patterns, which they can then transmit to the unmyelinated nerve fibres of the epidermis [256]. While this may not explain the exact localisation of the points and meridians as proposed by TCM, it does however propose a mechanism by which the stimuli by the needle puncture can be transmitted to the unmyelinated nerves present in the skin [257] and hence affect even spatially distant areas (256). In addition, other researchers have linked acupuncture to the concept of neuroimmunology (e.g., [258-262]].

One additional research avenue is the study of the location of acupuncture points or meridians, based on the effects of phytochemicals when applied at such locations. The most prominent such efforts concern the application of capsaicin, a phytochemical with numerous beneficial properties [263-267], in acupuncture points which was found to have favourable results [268-270]. Based on the past history of use of certain compounds at acupuncture points [116], other phytochemicals, with demonstrated health-related properties, such as kaempferol [271,272], curcumin [273,274], piperine [275], pinosylvin [276], and a host of natural compounds used in the field of oncology [277], could be used experimentally, to verify or dismiss such claims. Furthermore, it is known that acupuncture can measurably influence certain hormone levels in body fluids [278,279]; therefore, we propose that clinical trials could be designed, especially in cases where hormones or their analogues could be of therapeutical benefits, such as in the case of somatostatin [280, 281].

CONCLUSION

Studies on the detection of TCM meridians and acupuncture points have been ongoing, intermittently, during the last decades, by numerous different research teams, using different experimental setups. Whereas the majority of results is positive, i.e., TCM meridians and acupuncture points can be distinguished from the surrounding skin, due to theirs having different electrical properties, there exist a number of shortcomings in most experimental efforts. To be more precise, the different parameters used in most experiments do not permit an easy comparison of results, while the small sample size oftentimes used raises questions of statistical validity; in a number of cases there is also a lack of control factors. Even though we can conclude that it is possible to detect TCM meridians and acupuncture points using electrical properties, more research efforts are needed in order to standardise the experimental approaches and find a structural or functional basis for their existence.

Conflicts of interest and sources of funding

The authors declare no conflict of interest. No artificial intelligence automatically generated text was inserted in this manuscript, and no image was previously published in another journal or is under consideration for publication elsewhere. This research received no external funding.

Authors' contribution

Conceptualization, A.P., K.P.; methodology, A.P., K.P., A.I.; validation, A.P., and D.O.C.; formal analysis, A.P.; investigation, A.P., K.P., A.I., L.T., C.M.; resources, C.M.; writing—original draft preparation, , A.P., K.P., A.I., L.T., A.-T.P., C.M., D.O.C.; writing—review and editing, A.P., K.P., A.I., L.T., A.-T.P., D.O.C.; visualization, A.P.; supervision, A.P., K.P., D.O.C.; All authors have read and agreed to the published version of the manuscript.

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